Engineering Works and the Tidal Chesapeake

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INTRODUCTION

This paper discusses the tidal tributaries of the ocean and the coastal areas of the mid-Atlantic Bight and the ecological significance of engineering projects. While occasional reference may be made in this paper to remote sensing of problems engendered by engineering works on maritime environments and resources, principal efforts along those lines are reserved for the group discussion to follow.

The Chesapeake Bay drainage basin encompasses almost 65 000 square miles and provides space and partial resources for over 11 million people (1960) in New York, Pennsylvania, Maryland, Virginia, and the District of Columbia. Two other states, Delaware and West Virginia, to a lesser extent are part of this basin. Major residential, industrial and commercial, military, and recreational activities in the mid-Atlantic area make their demands on the environment and resources and contribute to the economic and social well-being of the populace. Certain social and economic disbenefits often accompany these activities. Population growth in the basin is increasing as are economic and social activities and other user activities.

Reference 1 includes many of the vital statistics on the Chesapeake Bay drainage basin. Numerous other studies in all fields have reported upon many natural, economic and social features of the Bay. Still others on these and additional subjects are in process.

While I have chosen to focus on the tidal portion of the Bay—in addition to the open coast and adjacent oceanic areas—the statistics of the tidal portion are no less impressive. The tidal area in comparison to the entire basin contains 7 million of the 11 million people in the basin, most of them on the western shore and the rest on the eastern shore of the tidal portion of the Bay.

The Bay contains attractive and extensive shorelines (estimated at about 10 000 miles), of which over 5000 are in Virginia. Vast expanses of water separate land masses, ports and harbors, commercial and industrial sites, and residential and recreational areas. Therefore, high-area demands for goods and services generate a large amount of engineering activity in this area (refs. 2 and 3).

Considerable local, state, national and international attention is being given over to problems of wisely managing the environments, their resources and their various uses in the active coastal areas. The coastal zone of the oceans is a major resource concern of all countries. The Chesapeake Bay is the largest estuary of the eastern coastal zone of the United States.

Among the multiple-use activities that have an impact on the features of the tidal Chesapeake and its tributaries is the prosecution of projects which result in fixed structures or morphological changes (often both) in the shorelines, bottoms, and waters. Oceanic or coastal areas are subject to the same uses or pressures.

Construction projects may be large—such as the Conowingo Reservoir or Chesapeake Ship Channel, or small—like a 200-foot bulkhead or pier on a residential shoreline. Large projects may have significant effects on tidal waters, depending on their proximity and nature. Small projects, ineffective by themselves, may collectively induce deleterious effects on environment. Large projects also may interact in this way.

All together, engineering activities are significant in the lives of estuaries and man (ref. 4). The Chesapeake tidal system contains many examples of their significance.

TYPES OF ENGINEERING PROJECTS

Engineering activities or projects can be classified in several ways other than by size. Should a project be located in or near tidal waters and be large and ecologically significant, it could be described as *direct* and have *large-scale effects.* If a project is nearby and small in ecological significance, it could be described as *direct* and have *small-scale* impact. Were its location or input removed from tidal environments, it could be described as an *indirect* type project. Its ecological impact would often be *small* but could be *large*, depending on project size and other features.

As indicated above, direct, small-scale impact projects can combine and have large ecological and economic impact. Projects can have an impact whether the activity is in the maritime area or many miles away.

An example of small indirect projects that can have collective impact would be the farm pond. This type of water and silt-retention reservoir, individually small, can be numerous and of large aggregate capacity, interrupting flows and storing large quantities of water and silt, taken together. The same multiplication effect occurs when numerous jetties or groin fields are built, or many small wetland tracts and bulkhead fields are filled in adjacent regions.

HISTORICAL TRENDS

Not until recent decades has there been much concern over the environmentally deleterious effects of engineering projects. Ecological awareness has only recently begun to match the need and urge for development and growth. Not only have the size and number of engineering projects increased since 1900, the ecological and economic impacts have enlarged.

In considering ecologically significant activities, we should consider the sizable canal construction, clearing activities, other transportation and agricultural works that were executed during early colonial and post-colonial times. Not all ecological effects have been perpetrated in this century. Some changes, indeed, were wrought by the American Indians who used fire for hunting.

The massive military works and municipal, industrial and commercial projects of the pre- and post-bellum period of the nineteenth century undoubtedly wrought their ecological changes. Comparison of early military and civil charts (around 1850 to 1860) and maps with those of the early 1900s reveals significant alterations in shorelines and bottoms. Since 1900 rapid and accelerating increase in number and size of projects has been the rule. Even cursory comparison studies carried to present times provide graphic proof of this trend. Since 1945 growth has been greatest.

It is worth noting that estuaries and tidal tributaries are often systems on their way to extinction due to long-term natural processes. While it is difficult to determine the exact stage of this process for any particular estuary at any given time, this factor must be considered. At some point man-induced effects could be ecologically as well as economically useful. We cannot overlook, therefore, purposeful and beneficial projects.

EXAMPLES OF ENGINEERING PROJECTS

A complete catalog classified by direct and indirect type, large and small size, for projects in the Chesapeake Bay drainage basin would be useful. However, it is not essential to present such a complete listing here, even if one were available or easily developed. Rather, I would prefer to name a few examples of different categories, presenting them by a scheme related to their intended goals or impacts on natural forces. The breakdown here is according to whether they result in geomorphological alterations or flow modifications; or whether they are defensive or retentive, are primarily related to building sites, or are structural.

Geomorphological Alterations

This type of engineering project results in changes in the topography of the bottom or shoreline, or provides connection between two bodies of water. Each has its environmental impact depending upon size, location, and the geophysical and biological features in the zones affected.

Aquatic geomorphological modifications are those carried out under the water, usually in or on the bottom.

Many small channels serving residences, piers, and minor waterways exist, are being built, or are projected. Private piers and small public and private marinas and landing points exist by the thousands. Usually larger government-developed harbors occur by the hundreds in the Bay region. Density is greatest in heavily populated and industrialized areas.

Intermediate-sized channels exist in almost every major eastern and western shore river that is tributary to the Bay and these channels number in the dozens. There is hardly a tidal stream or reach in the entire Bay which does not feel the bite of the screw, scoop, clamshell or rotary-head dredge.

Major channels and harbor projects include the Chesapeake Ship Channel leading up-bay to ports on the Rappahannock, Potomac and Baltimore harbor, and the Hampton Roads access channels and the Hampton Roads harbor area. These are extensive and continually maintained (figs. 1 and 2). All have been under frequent consideration for deepening and enlargement. Deepening usually produces geophysical and biological changes of greatest magnitude. Maintenance dredging also contributes its effects, depending on the extent of basin alteration, method of dredging and the method and location of spoilage areas.

Spoil bank and overboard disposal areas are types of engineering developments that are frequently associated with dredging projects, usually as an important ancillary activity to channeling. Early practices of spoiling immediately adjacent to a developing channel have diminished as engineers began to realize that rapid filling usually resulted. Remedial off-site spoiling has raised costs of spoil disposal, whether onshore or overboard. Off-site spoiling has increased the demand and need (the two may be different) for spoil areas.

The proposed James River navigation project—the channel from Richmond to the nearby Atlantic—is an excellent example of a major channel improvement project requiring extensive off-site disposal areas. Many of these will replace spoil sites in reaches where overboard disposal was once extensively practiced. To merely deepen the channel from its present 25 feet to 35 feet will necessitate disposal of 46 508 000 cubic yards of spoil in the reaches above the James River Bridge at Newport News. Earlier practices of overboard disposal are being actively discouraged in many places. Yet disposal in low-lying wetlands seems less suitable.

To establish the Chesapeake Ship Channel in the Virginia portion of the Bay at its 42-foot depth required disposal of 14 309 200 cubic yards of materials. Studies by Brehmer (ref. 4) made during and after deepening of the Rappahannock shoal reach indicated that neither the dredging nor the overboard disposal practices produced much ecological damage. Despite this and other similar findings, there is obviously a limit to overboard spoilage in a bay as shallow as the Chesapeake. Indeed some areas are filling so rapidly by natural process that overboard spoil disposal must be strongly discouraged.

Channel and turning basin improvements in Baltimore harbor and Hampton Roads likewise generate vast amounts of spoil. So great is demand for spoil disposal space that the Corps of Engineers must seek additions to the 2500 acre Craney Island disposal area. This area will have reached its capacity in the short 30-year period between 1949 and 1978 (fig. 2). It will eventually be filled to a level 18 feet above mean-low water.

Ecological and economic problems of spoil disposal are massive and worthy of much more scientific study and engineering examination than has been accorded them to date.

Terrestrial geomorphological modifications are accomplished on or into highland or fast land.

Terrestrially centered projects are no less numerous than channels since many residential and commercial sites result from filling out from former shorelines or cutting channels into the land. Three types are easily distinguishable: (a) those that bridge land barriers and open communications between bodies of water, (b) those that result in new land, and (c) artificial dead-end waterways designed to produce waterfront. The last two may be collectively called shoreline modifications.

Connections between water masses (canals, gaps, and cuts) are projects that are least numerous but usually sizable. Many are vintage. For example, in Virginia the Dismal Swamp Canals (ref. 6) connect the lower Bay to Albemarle Sound. Canals connect the Elizabeth or Nansemond River on the northern end and the Northwest or Roanoke River on the southern end. The cuts and gaps, such as Dutch Gap, which were constructed to shorten the tidal James below Richmond (fig. 1) are also examples of ancient canal projects. Efforts to develop these connections date back to 1785. Remnants of many other canals exist in the Chesapeake Bay drainage basin (ref. 6).

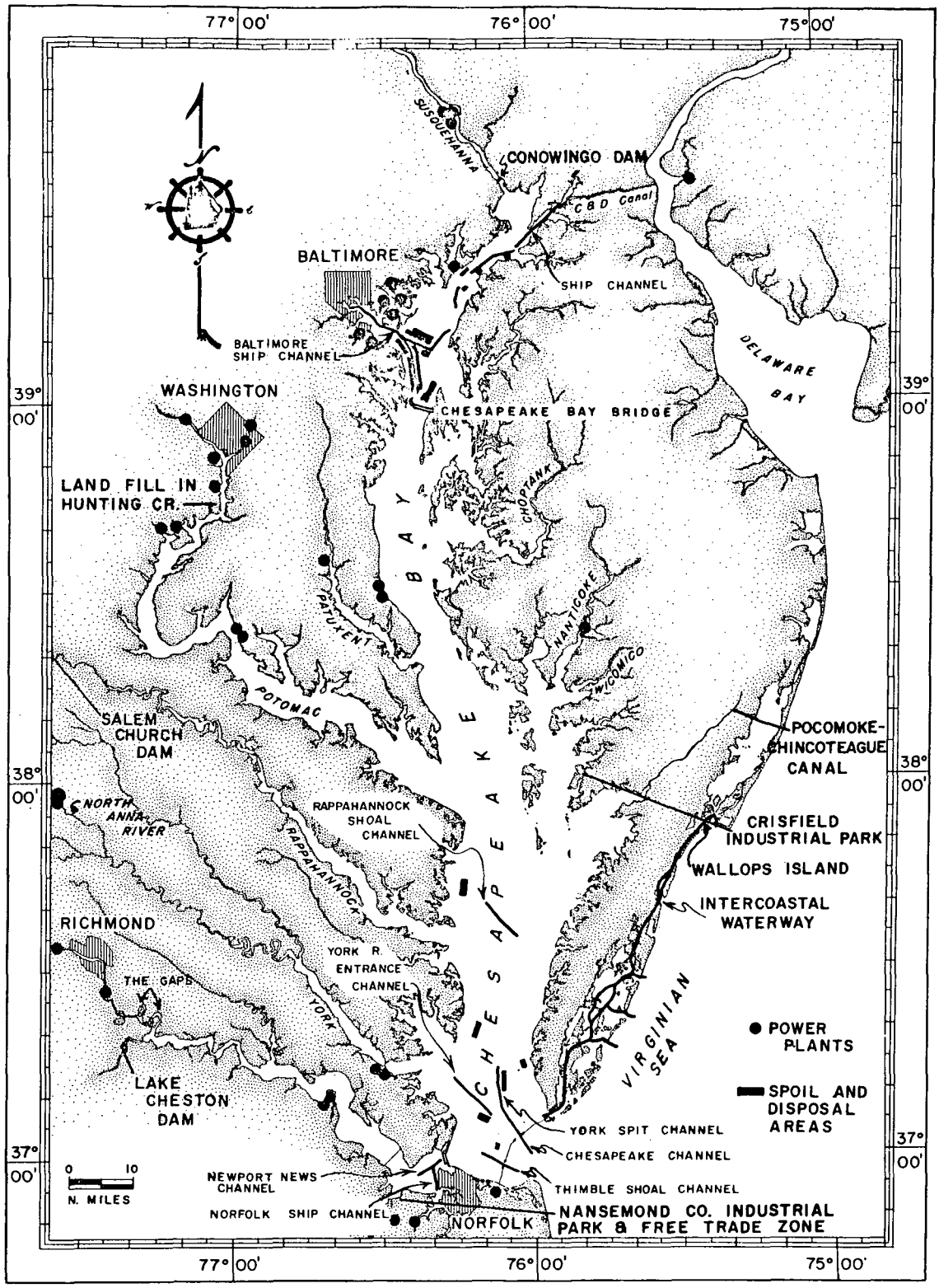

Figure 1.–Chesapeake Bay showing certain engineering projects.

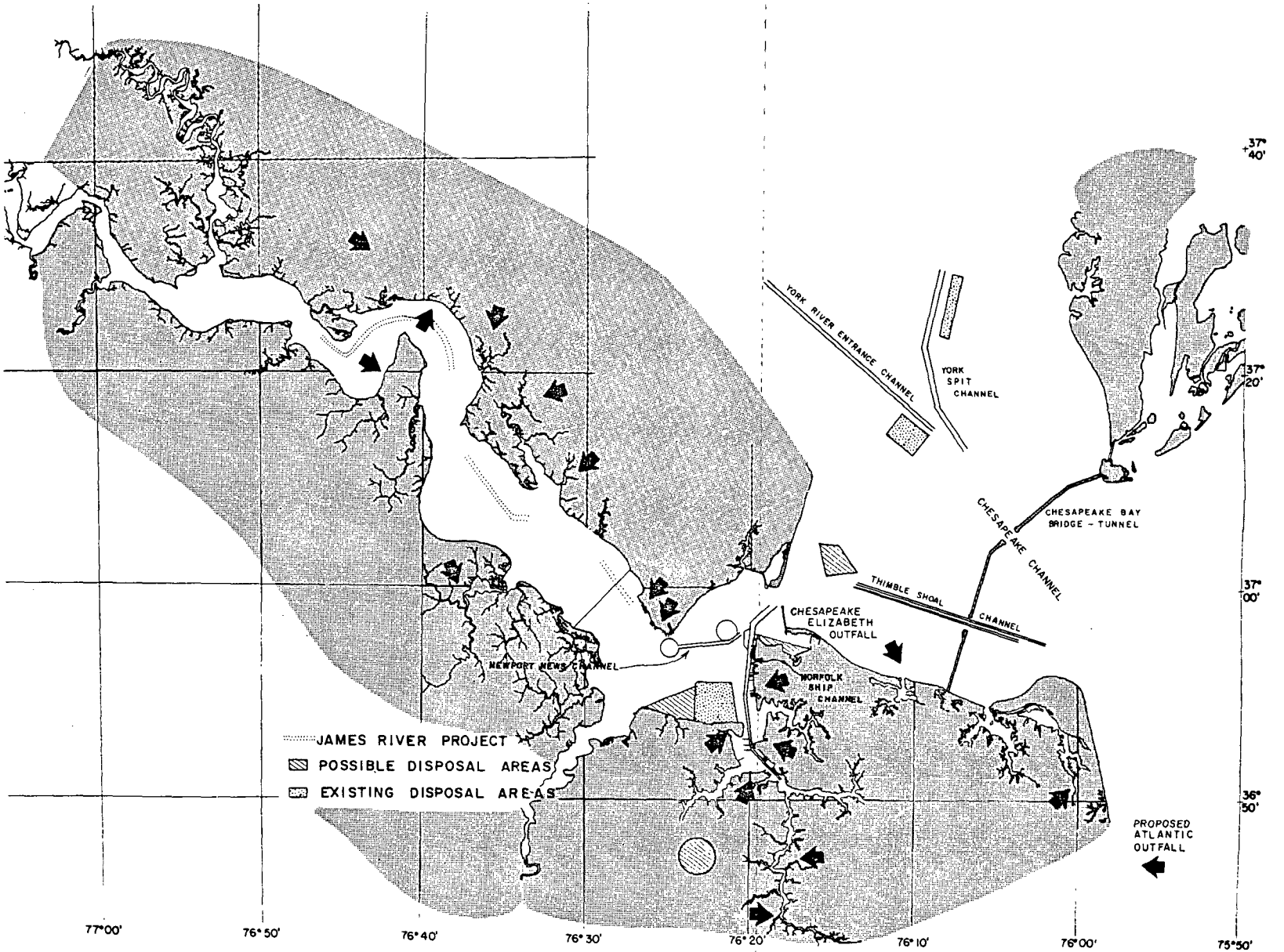

Figure 2.–Outfalls, channels, and spoil areas in the lower James River.

The Chesapeake and Delaware Canal is the most celebrated of the recent land-cut canal works in the Chesapeake Bay region, though the Intracoastal Waterway of the DELMARVA peninsula is again quite active (fig. 1).

The proposal to deepen the Chesapeake and Delaware Canal from its presently authorized depth of 35 feet to 42 feet has drawn much attention because this man-made and currently lock-free waterway connects waters of differing salinities–(ca. 1 percent on the Chesapeake side and 5 percent on the Delaware side). Such deepending would divert about 1650 cubic feet per second more fresh Susquehanna River water from the Chesapeake Bay to the Delaware Bay. There has, therefore, been concern for the effects on salinity distribution in Maryland and Virginia waters of the Bay. The Susquehanna supplies the Chesapeake with almost 50 percent of the entire fresh water inflow from rivers. Significant reduction of inflow by diversion through the C and D Canal could cause significant salinity changes and related problems to the Bay area. Similar shunting to provide fresh water in any sizable amount to localities in New York, Pennsylvania, New Jersey, or Delaware would have similar effects. Several projects designed to remove fresh water from the Susquehanna are, indeed, extant.

The Intracoastal Waterway extending from Ocean City inlet on the sea side of Maryland to Fisherman's Inlet on the Chesapeake Bay connects the high-salinity seaside lagoons and bays to each other. Classed as an alongshore canal by Cronin, Gunter and Hopkins (ref. 4), this project is under consideration for maintenance dredging and modification.

The dike and fill projects which extend fast land out into areas once covered by wetland or water fall in the shoreline modification category. Seaward movement of land is the usual direction of this type of engineering project. Occasionally, however, waterfront is developed by dredging canals into fast land–the third type mentioned in the listing preceeding this exposition. Huge turning basins at the ends of these cuts are often stagnant cul-de-sacs.

It is difficult to estimate the number and total extent of landfill and waterfront-cut shoreline alterations in the Chesapeake Bay. Even more difficult is it to enumerate the purposes for which these smaller projects were made. The detailed analyses which would yield the basic data are only now being done in the lower Chesapeake Bay (ref. 3 and Wass and Marcellus[1]).

Massive projects which are developed for large-scale residential, commercial, or industrial purposes are more easily detected and enumerated because of their higher visibility. Since demand for waterfront facilities is greatest around centers of high population and commercial or industrial activities, the main focal points are easy to detect or predict. These regions include Baltimore and adjacent areas, Washington area and the adjacent upper Potomac River, Richmond-Hopewell area in the upper James River, and the Hampton Roads area at the mouth of the James River. Virginia Beach and Ocean City are also active, especially featuring finger-type or Venetian waterfront development (ref. 4).

Estimates of waterfront usage and rates of landfill in Virginia areas are provided in Wass and Wright (ref. 3). Similar reports have been developed by Metzgar and his associates for upper Bay waters (ref. 7).

In the Hampton Roads region, shoreline extension for commercial reasons has been most extensive, with marked changes in shoreline contours since 1850 and even earlier. Overlaying of charts from 1850, 1900, 1930, and recent years clearly shows the shallows of the lower James to have been much reduced in areas by bulkheading and landfill, and the shoreline to have been made much more regular in outline.

The Eastern Branch of the Elizabeth River to Willoughby Spit reach, the Newport News to Old Point Comfort reach and Western Branch of the Elizabeth to Craney Island reach–all provide excellent examples of this type of change. Hundreds of landfills of all sizes have been responsible.

The Craney Island spoil disposal area mentioned above is a large one (fig. 2). The possible point waterfront development at Newport News opposite Hampton Roads is a smaller one. Likely landfills upstream of the point at Newport News will fill much of the remaining shallow area between the point and the James River Bridge. Together, these large and small Hampton Roads area projects greatly affect economic and ecological scenes. They produce large changes in the morphology of the shorelines and, likely, effect profound modifications of currents in the lower James River. All should be examined during design and presented in the James River Hydraulic Model–jointly operated by Virginia and the Corps of Engineers–at the Waterways Experiment Station at Vicksburg. Baltimore harbor and adjacent Patapsco River have been much affected by similar projects.

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[1] Wass and Marcellus: Personal communication.

As indicated above, the Ocean City-Rehobeth Beach region of the eastern shore has experienced considerable finger-type and other extensions of shoreline. Similarly, Virginia Beach is site of residential and recreational landfills or cuts. A few are located elsewhere on the lower peninsula of Virginia and in the northern bay of Maryland. Pressures for their increase in numbers, size and geographical spread will surely grow. Wetlands of the Norfolk, Chesapeake and Virginia Beach areas have almost disappeared as a result of dredging and filling. Wetland elimination continues, and this trend is apparent in other areas of high activity.

New proposals for wetland filling and extensions of island and mainland shorelines are submitted weekly to state and federal agencies for permit approval. Scarcely a month goes by without a Goodwin-Island, Mumfort-Island, Smith-Island, or similar project being proposed. So rapidly has this trend developed and burgeoned that both Maryland and Virginia have become alarmed, along with all other coastal states. Assemblies and agencies of both states seek better methods of planning and management of wetlands, shorelines and shallows. The files of management agencies such as the Marine Resources Commission, which grants permits for use of state-owned bottoms, and the Water Control Board and Public Health Department are full of proposals for more projects. The Virginia Institute of Marine Science has files full of environmental impact statements on these projects. Federal agencies such as the Corps of Engineers and Environmental Protection Agencies are no less pressured.

Flow Alterations

Engineering projects that retain water such as reservoirs result in changes in patterns of flow of water, usually fresh water. In some, only a short-term alteration in flow results during initial filling periods. Long-term changes from these, usually low, unregulated dams are most often minor. Other dams are constructed so as to modify or regulate flows on an almost continuous basis.

Dams and reservoirs are of several construction types, sizes and purposes. They are mainly for water supply, hydroelectric power, flood and flow control.

In the coastal plains region, reservoirs are usually shallow and devoted to water supply. Low topography generally prevents large volume storage. Even so, they may considerably change the available fresh water to the tidal tributaries on which they are located. As the water is drawn into municipal and industrial mains to be discharged from the waste-treatment outfalls considerably downstream of the headwaters, salinity as well as current patterns may be altered in both bypassed and receiving reaches. These direct effects may produce marked ecological changes in each.

The Elizabeth River system of the Norfolk-Portsmouth-Chesapeake area is one which has been altered in this fashion. Part of the flow from its headwaters, limited though they are, are trapped in upstream reservoirs and diverted through the water supply mains, put to use, and discharged again through the sewers into the lower reaches of the river. The diversion from Diascund Creek of the Chickahominy system to the Newport News-Hampton area is a longer-distance example of this type of project.

On the lower reaches of the fresh water portion of the Susquehanna River, a series of reservoirs, the biggest being the Conowingo Dam, are used to supply water to Baltimore city and environs. Outfalls pour into the Patapsco and neighboring tidal waters. The Conowingo diversion is one of the largest in the Bay system (fig. 1). An interesting side effect of the large reservoirs and their operation is the abnormal temperature regime induced below the dam when cold and oxygen-deficient water is released through the outfalls located below the epilimnion or the upper thermally stratified layer of the lake in summer and early fall.

Introductions of fresh water pumped from the depths of subterranean aquifers that would not normally enter estuarine areas may reach significant proportions and change salinity patterns. These injections occur from outfalls of large industrial and municipal water users. Several are known in the tidal James.

At times, both flow diversions of surface water and injections of subsurface waters are required.

Usually located above the fall lines, or upper limits of the tide in the Bay tributaries, in the Piedmont or mountainous regions of the Chesapeake basin, multipurpose reservoirs are of varying sizes and types. In every instance, they perform several functions. The farther they are above the fall line the less their influence on tidal waters, as a rule. For example, the proposed Gathright Reservoir, a 344-square mile drainage basin (363 000 acre-feet) on the Jackson River of the James, will have no influence on distribution of salinity in the tidal James. Benefits, though, to water

quality in the reach below Richmond are supposed to accrue from dilution.[2] As far as is known, multipurpose Smith Mountain reservoir has little influence on the tidal reaches of the Roanoke River drainage system despite its large volume.

Larger upland reservoirs, numbering in the hundreds, abound on the major tributaries of the Chesapeake drainage basin. Constructed for hydroelectric power, flood control, water supply and other purposes, these units also are capable of changing seasonal patterns of flow, reducing or increasing peak or minimum flows, depending upon operations. They also remove suspended matter and otherwise change the quantity and quality of water available to the lower basin.

The changes produced by large upland reservoirs can be deleterious, i.e., allow pest-bearing, high-salinity waters into shellfish-producing areas formerly free of such pests. The changes can be beneficial, i.e., improve water quality by augmenting summer low flows or reducing shellfish pests by lowering estuarine salinities during their breeding season. As an example, the Salem Church Reservoir (fig. 1) could, if properly designed and operated, be used to increase oyster production by controlling their pests as a result of salinity manipulations. While one would hardly build an expensive dam to achieve this one objective, it could be a significant secondary benefit, were the project soundly justifiable on other bases. Indeed, a study by VIMS' scientists (ref. 8) has indicated just such a possibility.

Clearly, many factors must be considered in ascertaining actual or potential effect. These include the number of projects as well as volume of water stored. For example, many small ponds are constructed to retard erosion, clarify streams, supply water needs of livestock, and for local recreation. These ponds can alter water inflow patterns, especially in dry months and if they are working effectively, they can dry up the flow of sediments which once served to nourish beaches as well as fill channels far downstream.

There is little question that the cumulative effects of thousands of small reservoirs are felt in tidewater. Their effects are felt, not in spring when early rains and melting snows swell the down-rushing flow to near flood levels, but in the seasonally dry period of late summer, fall and winter.

Cumulative evaporation has to be another factor in flow modification, especially from the host of shallow reservoirs involved. A large volume of water, formerly retained in the drainage basin, is lost through evaporation from reservoirs. This shortening of the hydrologic cycle can also modify weather as well as water flows.

The larger the reservoir and the nearer the tidal reaches, the more significant the effects on those waters may be. Especially significant may be those changes in fresh water-salt water balance during the period required to fill the reservoir. Exemplary of this is the North Anna Cooling Reservoir (figs. 1 and 3) on the Pamunkey River tributary to the tidal York River. Due to the large volume of the impoundment in relation to the flow of the stream, time required for filling is estimated at from two to three years. Without proper planning, a significant alteration of salinity patterns could result during the period. Since spawning of certain fish and growth of shellfish is often dependent upon proper salinity levels and patterns, estuarine ecologists at the Virginia Institute of Marine Science have expressed strong concern over biological damages expected to result from the filling. They, and others are concerned, lest the release schedules and volumes of water available for release from this reservoir be insufficient to maintain proper salinities downstream. Unfortunately there are no salinity standards against which to gauge legal requirements for reservoir releases or on which to base judgments of undue interference with ecological norms.

Salinity is an aspect of water quality usually of far greater significance in estuaries than dissolved oxygen. This consideration is an important shortcoming in Virginia's regulatory arrangements. Statements of the nature and extent to which salinity can be modified must be worked out for each major tributary and region. In many instances additional field and laboratory research is required for salinity standards to be properly set but eventually we must establish such management guidelines. Effective mathematical and hydraulic models must be developed and utilized in this work.

It is difficult to determine or predict the downstream effects of a single large reservoir. It is *infinitely* more difficult to predict or detect the synergistic or the counterbalancing effects of numerous reservoirs of all types on the lower reaches of a river system. Quantity and timing of water flows are of concern; also aspects of water quality such as turbidity, nutrients, and temperature may be influenced by reservoir construction and operation. Any or all may have effects, sometimes profound, on receiving tidal waters far downstream.

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[2] VIMS, official communication.

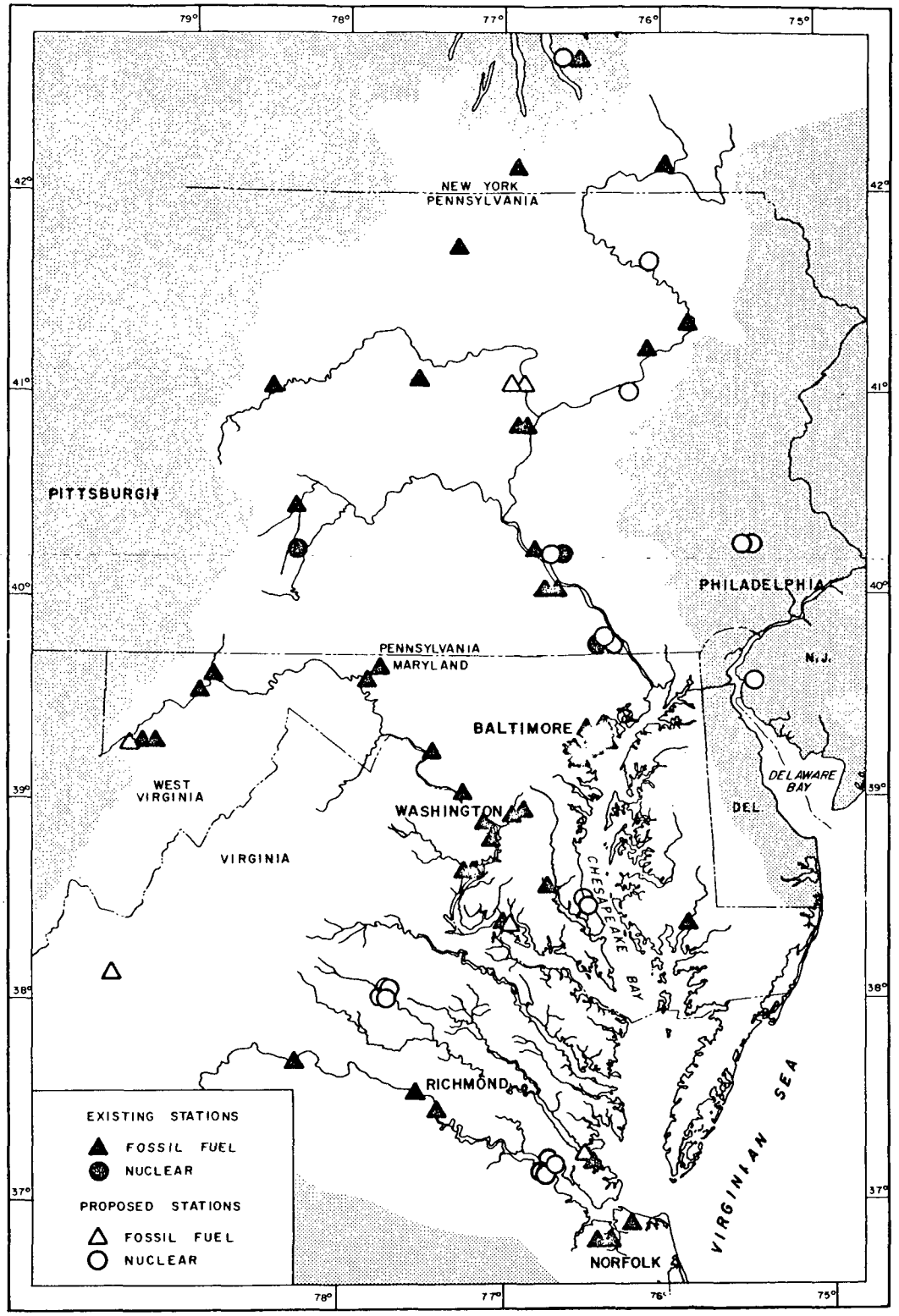

Figure 3.–Present and proposed plant sites in the Chesapeake Bay, as of July 1971.

Hence, engineers, ecologists and geophysical specialists must carefully consider these aspects in designing single reservoirs and systems of reservoirs. A glance at the compendium of actual and potential reservoirs on the upper James basin now under consideration by the Norfolk District of the Corps of Engineers serves to illustrate the complexity of the problem. Couple these difficulties with those introduced by geometrical changes in the tidal reaches far downstream and one has a fair idea of the tasks facing these groups.

Occasionally special problems will prompt massive engineering works. Examples of these problems include (a) protection from flooding of part of the City of Providence, Rhode Island, by storm-driven high water; (b) exclusion of salinity from the upper reaches of the Delaware to protect fresh water supplies; and (c) meeting the anticipated need for large amounts of fresh water for the Hampton Roads cities. Proposals for massive engineering works to solve these special problems include (a) Hurricane Barriers across various places in Narragansett Bay; (b) the Saltwater Barrier across the Delaware Bay at Deepwater Point; and (c) the once-suggested tidal exclusion dam across the Chesapeake Bay.

An engineering project which has arisen several times in the lower Bay region has been the scheme to construct a dam at Jamestown Island, or some similar location. The dam would convert the James above that point into a large fresh water reservoir and provide for deeper draft vessels upstream. Needless to say, such a project would result in great changes in the physical, geological, chemical, and biological features above and below the dam.

The Narragansett project resulted in construction of an hyrdraulic model to examine its impacts and to consider design features. After much testing and design modification, a local protection scheme was chosen from among the options tested. Called the Box Point Project, this barrier has been used several times.

The Delaware salinity barrier was examined in the Delaware Bay model and later abandoned. The Chesapeake Bay proposal has been rejected more-or-less summarily. But the James proposal, while still primarily a paper project, reached the point at which it was officially commented upon in an environmental statement by the Institute to the Governor's office.

In other estuaries, underwater training barriers or wiers have been proposed or carried into actual project stages, but I know of none in the Chesapeake Bay. Certainly overboard spoil disposal activities may have created barriers which affected circulation of bottom waters, at least for a time, but these have been accidental. In time, such projects may come into being.

Defensive or Retentive Structures

Over the centuries, amateur and professional engineers have developed many structures of differing designs, materials, and methods of construction to prevent moving water from undermining and eroding fast land. These structures primarily exclude or moderate the dynamic forces of the sea or hold the land by stabilizing it; the ultimate goals are (a) to stabilize or build shorelines, or (b) to protect works of man both in the water (channels) or on land (buildings and other structures).

Among the various engineering structures, jetties and groins are used to build shorelines, prevent shore and bottom erosion, support bulkheads in certain situations and prevent channel filling. The majority of jetties are small in size, extending less than 100 feet seaward. However, large jetties are frequently used to protect the entrances to harbors and inlets along exposed shores in various places in Chesapeake Bay and on the exposed open coast. Those at Sandy Point (western terminus of the Chesapeake Bay Bridge near Annapolis), Matapeake (eastern terminus of the ferry which the Lane Memorial Bridge replaced), Smith Point (near the mouth of the Potomac) or Rudee Inlet (Virginia Beach) are examples. That at Kiptopeake made of hulks of World War I concrete transport vessels is one of the largest and most unusual in the region.

Generally speaking, the biological effects of jetties and groins are as local as their geophysical effects. At times, however, large jetties or extensive groin fields (fig. 4) serve to starve shallows and shorelines far downstream (in terms of littoral drift). Starvation may continue for some time depending upon local bathymetric and current patterns. Small jetties are usually insignificant in ecological influence.

Mentioned above under considerations of dike and fill activities, strategically placed bulkheads may alter patterns of movement of soil, sediment and water. Interestingly, also as indicated above, estuaries–like many other natural systems–are often systems on their inevitable course to extinction. Factors in this extinction process include background changes, such as rise and fall of sea level and subsidence and uplift of related land masses. Man can allow

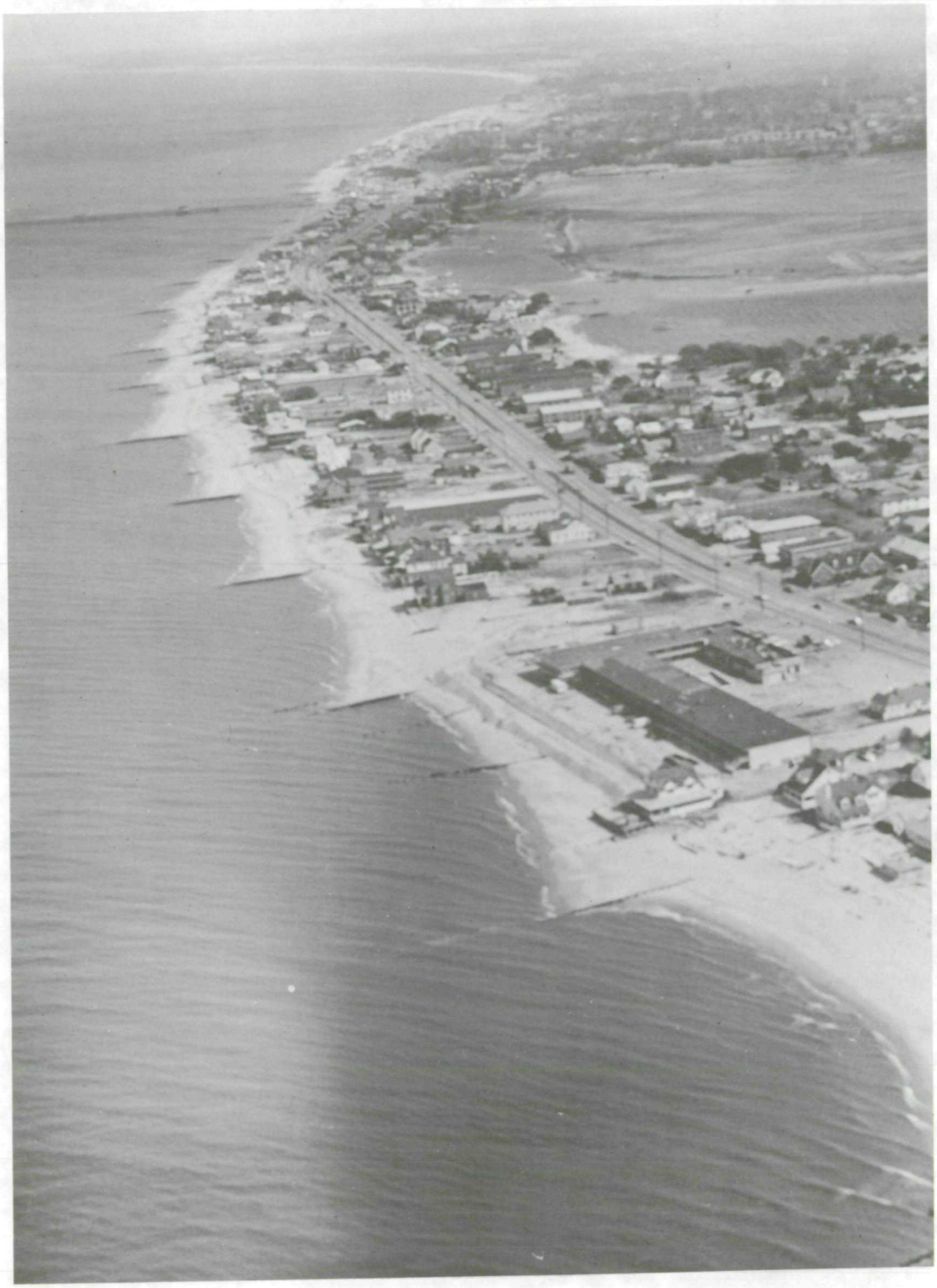

Figure 4.–Groin field at Willoughby Spit.

estuarine systems to progress to oblivion according to their natural procession and at uninterrupted rates. He can do so by not intervening or by counterbalancing interventions. He can hasten the downward process toward elimination by making engineering changes and additions which speed the processes of filling and eutrophication.

Man can, alternatively, reverse the process of extinction by interferring with the balance of erosion and sedimentation through deepening channels and other bathymetric alterations. And he can reverse other processes–geological, physical, chemical and biological–which lead to eutrophication of estuaries. With these possibilities involved, the technological and engineering capabilities of man can be applied to speed the eventual demise or undertake corrective and remedial projects even on large systems like the Chesapeake Bay. We must have the will to do so and arm ourselves with the necessary plans, funds and tools to do so. Among the important factors are

(a) Adequate scientific and technological knowledge of the estuarine system

(b) Adequate simulative and predictive devices like mathematical and hydraulic scale models into which the changes can be introduced and examined deliberately

(c) Creative and responsible organizations and individuals that can weigh and advance the opportunities that present themselves

Uninterrupted natural change can be and frequently is as destructive of specific natural systems as alteration by activities of man. In many instances, only the rate of change and not the results are affected. I do not advocate destructive change or deny the scientific and aesthetic value of observing uninterrupted natural systems. I decry the activities of man which accelerate destruction of those systems. I also urge reason and point out that, given knowledge and the proper tools, we can engineer constructively.

It is not necessary to depend solely upon concrete, bricks, blocks, iron or wood to stabilize beaches or shorelines. By judicious placement of plants and sand, perhaps aided by frail but effective sand fences, we can slow or reverse the seaward or erosive movements of sand. Obviously alterations of geomorphological and biological systems will occur. The environmental and resource significance of such changes will vary according to design, magnitude, and conduct of the project.

Other Aspects of Sediment Movement

We have discussed specific engineering structures or procedures which serve to stop, slow, or reverse the natural procession of sediments into and through estuaries like the Chesapeake Bay. Other human activities which may have marked influence on sedimentation are (a) agricultural operations, (b) forest harvesting, (c) site preparation for industrial, urban or commercial developments, and (d) highway construction. Some erosion from extensively active agricultural or construction sites is probably inevitable but significant control is possible and essential in all cases.

In areas of high rate of urbanization or large construction and agricultural activities, turbidity of streams receiving runoff is often very high. It is not uncommon for the upper tidal Potomac and upper tidal James to run brown or red from soil deposits, even after a light rain. Public authorities need to be alert to this type of contamination. Excessive turbidity not only damages production of oysters but also reduces photosynthetic activity, to say nothing of increasing rates of deposition in channels and bottoms.

As with salinity we do not as yet possess adequate water quality standards for turbidity, color, or sediment load in tidal rivers. Such standards should be developed since it is essential to prevent damage from this major contaminant.

Structures

Introduction of structures in tidal, and other flowing waters, inevitably induces alterations in flow patterns–direction and speed of currents, and related natural parameters. Aside from their physical effects, changes such as scour and fill, may be produced in geological features. Additionally, plants and animals may be attracted to the above substrate and the shelter and sustenance these above-the-bottom structures offer.

It has been postulated that even open-faced structures such as pier-borne causeways may interfere with in and out movements of migratory fishes much the same as large-mesh hedging trains or directs them into pounds or traps. The reality of this postualte has not been effectively examined in the Chesapeake Bay, which now has one of the longest of such structures in the world. Thus far, the Chesapeake Bay bridge tunnel (figs. 1 and 2) has been quite effective as a net for military and commercial vessels too large to pass through its openings. However, there is little real indication of interference with anadromous or catadromous fish, or even longshore migrants.

Undoubtedly, the bridge-tunnel at the Capes, those in the Elizabeth and the James, the Chesapeake Bay bridge (Kent Island to Sandy Point, Maryland) and the James River bridge exert mechanical influences on the water. Again, the significance of such influence has not been measured—either out of indifference or inability to do so. Patently, interference differs according to the nature of construction. Solid-fill and open-faced causeways are obviously very different in effects.

Islands that are solid-fill causeways are engineering objects that are more profound in their influence than the "pierced" piered ones, acting to force waters to move around them and assume different current patterns than formerly. Many have noted the patterns of refraction and reflection caused by groins and jetties. Influence depends upon the direction and force of the moving water. If solid-fill causeways are extensive, with few passthroughs they may act as dams to storm water or even resist normal tidal flows. Most common in marshy areas, such causeways may influence not only geophysical features but can also interfere with movements of marsh animals (mammalian, piscine and avian) or even with flux of nutrients from wetlands into adjacent waters.

Examples of such projects abound in the Chesapeake region. For instance, Maryland's Chesapeake Bay bridge (fig. 1) employs short, closed causeways which act as jetties. Many of the bridges in shallow or marshy estuaries of the eastern shore, bayside and seaside, use long-closed, earth-fill causeways interrupted only by draw or swing bridges over major waterways. Often injudiciously placed culverts connect the interrupted drainage areas. The mainland-to-Chincoteague-Island bridge consists mostly of Earth-fill and solid causeways. Similar projects occur on the western shore.

The Chesapeake Bay bridge tunnel from Cape Charles to Virginia Beach employs open-pile causeways, but encompasses four large islands as terminals for the under-channel north and south tunnels. These islands are large, extending about one-fourth of the way across the major Bay opening from Fisherman's Island to the Bay shore of Virginia Beach. They must have consequently produced certain geophysical effects beyond their local realms. Undoubtedly, changes have been wrought in Bay-mouth circulation. However, neither we nor the Environmental Sciences Service Administration, now a part of the National Oceanic and Atmospheric Administration (NOAA) of the Department of Commerce, have been able to establish any other than high local effects around the pier's causeways and islands themselves.

Large open-face causeways and piers interfere with circulation to a much lesser extent than solid-fill causeways and quays. Nonetheless, they do cause alterations in current flow. Obviously, these changes are greatest near the structure.

As an example, the causeway pilings of the Chesapeake Bay bridge tunnel number approximately 850 in each row. Their faces, which are 4½ feet in diameter plus the tunnel islands aggregate sufficiently to narrow or occlude the opening of the Bay by over 25 percent. As indicated above, changes other than local ones have not been observed. Among those that could have occurred is alteration of timing of flow through the capes, with consequent changes in tides, increased turbulence and increased substrate for attached plant and animal organisms.

Additionally, as fouling organisms increase, so also will diameters of the obstructing pilings grow—resulting in some further obstruction. Not only will pilings grow in cross-sectional dimensions, but roughness factors will also be increased by barnacles and other attachments.

These large mixed communities of attaching organisms are spaced widely across the Bay mouth. Although their contributing larvae, wastes and other biochemical materials may cause changes in the biota of the lower Bay region, their influence on the geographical aspects remains not clear.

If we had the model of the Chesapeake Bay now being developed by the Corps of Engineers, we might have been able to examine the possible effects of the bridge-tunnel—at least those relating to features such as current patterns, tidal levels and sedimentation which can be simulated in such models.

Bridge-tunnel complexes include those existing or under construction between Willoughby Spit and Old Point Comfort in the Hampton Roads portion of the lower James estuary, or those associated with the Chesapeake Bay bridge-tunnel. Whether or not part of a larger complex, tunnels have little besides transitory ecological effects unless

constructed in such a way as to protrude above the natural bottom, thus producing a sill. Largest effects occur near the points where they emerge from below the sea floor and constitute a physical impediment to currents, silt and debris.

More importantly, by establishing controlling depths, if placed across main channels—as they usually are—tunnels may have a marked effect on the commercial future of the body of water affected. Long-term economic and sociological significance of tunnels therefore cannot be ignored.

Municipal and industrial water supply systems and waste water treatment plants frequently involve sizable structures that train, engulf, or disgorge large volumes of water and entrained materials. In many, both intakes and outfalls extend seaward some distance, depending on local conditions and design. Secondary wiers and other training structures such as canals may be involved.

Obviously, local current patterns are modified by flows at intakes and outfalls, especially of large water-using facilities like SES power plants. Not infrequently, intake flows are so great as to constitute suction pumps capable of diverting and straining large volumes of water. For example, at full capacity the Calvert Cliffs nuclear power plant will strain 5600 cubic feet per second or 3 456 000 000 gallons per day of water (Maryland Academy of Sciences, 1970). Such huge structures could affect local fish populations and cause problems for the plant operator because of fish intake. Hence this ecological and economic factor must be considered in design and operation of such units.

Intake and outfall structures may serve as jetties or groins if extending above the surface or may serve as training barriers if submerged. The many SES stations throughout the Bay area (fig. 3) all present aspects of this sort, no matter the type of fuel.

As municipalities and associated commercial activities grow, so does the need for large underwater discharge systems or outfalls (fig. 2). Increasingly, the tendency is to collect waste waters into large trunk lines for discharge into the large-volume waters of the main bay or the ocean. Geophysical and biological effects are possible from the effluents and from the "fishing" or blocking action of such structures.

Mining

Mining of sand, gravel, shell and other materials from the floor of the Bay and its tributaries is not construction. Since engineering is involved and there is considerable similarity between channel dredging and mining, brief mention seems justified. Several companies operating around Chesapeake Bay mine sand, gravel, and shells. Some operate intermittently for special purposes such as shell planting. Others regularly mine for long-term and continuing building material supplies, beach nourishment, livestock and poultry feed, cement manufacture, chemical processing, etc.

Mining does result in alteration of the morphometry or bottom topography of the area being mined. Such changes may be only local, leaving deep holes to be filled by sedimentary processes later. They may, on the other hand, be more significant and fill far from the area of direct mining, i.e., secondary effects. Secondary effects such as (a) slumping and erosion of adjacent shorelines due to undermining or (b) current alteration may be significant, depending upon local conditions and project details. Beside direct disruption of the bottom, its inhabitants and their life processes, activities such as shellfish culture may also be damaged.

Of course, dredging operations include (a) dredging for crabs, oysters and clams, (b) hydraulic, clam shell, rotary-head, and other dredging for channels, and (c) mining. These operations all entail disturbances of the bottom, roiling of sediments, and overboard discharge of silt and other sedimentary materials.

ENVIRONMENTAL PROBLEMS RELATED TO ENGINEERING ACTIVITIES IN THE BAY

We have seen that the Chesapeake Bay is host to many engineering projects and activities. These range from small channels, bulkhead and fill projects, and piers, to massive or international channels, multiacre bulkhead and fill projects and 18-mile long bridge and tunnel complexes, with all sizes and types between. Each interacts in several ways with the environment in which it is placed. At times these interactions are local and insignificant, at others widespread and large. Size of the project is important in determining its ecological impacts, yet numerous small projects can produce large and multiple, even synergistic, effects.

Projects in the vicinity of the tidal portions of river systems such as the James, Potomac, or lower Susquehanna are likely to have the greatest impact. Reservoir construction and operation far upstream in the mountains or plateaus may also cause damage or improvement in estuarine conditions.

The purposes of engineering projects vary as do their sizes. Variability complicates problems of project engineering and environmental matching, but constructive uses can be made of appropriate project mixes. Understanding interactions caused by variability in purpose, size, and numbers is important because engineering projects and activities can interact. Interactions can produce subtractive, additive, or synergistic effects on the marine and other environments and the resources.

That ecological effects of engineering works vary is clearly established. They need not be deleterious but can be beneficial to the environment. Immediate and long range utility of the work is variable according to our ability to "design in consonance with nature."

Engineering works favor certain locations. Usually these locations relate to location of a resource or other favorable natural feature, or to the distribution of people and their activities. Hence, potential sites are often identifiable far in advance of actual prosecution of the project.

Unfortunately, man's engineering projects tend to congregate. In the Chesapeake Bay, man and his works usually occur where important environments and resources are already located; this doubles the hazard to natural systems (fig. 5). Pressures for increasing numbers, sizes, and types of engineering projects and activities are certain to increase. The rate of increase will be especially rapid in the coastal zones all over the world. The Chesapeake Bay is a resource and environmental system under increasing stress from engineering activities.

By now, many informed people are concerned over maintaining the quality and quantity of our environments and resources to the maximum extent possible, consistent with meeting the needs of the human and other inhabitants of the Earth. Control of population pressures is an important leverage point in any environmental control system—one which cannot be dismissed in the search for overall solutions; yet the problem at hand concerns bringing engineering works of man under better control.

Many environmentalists and engineers are convinced that we must do a better job of matching project to environment while minimizing adverse or maximizing beneficial aspects—including economic balance. They also are convinced that we must determine long in advance suitable sites for the given types of activities, and the location and number of sites that must be left alone to preserve the essential qualities and quantities of environments and resources. Preservation of quality and quantity and improved engineering requires better understanding of environments and resources and their inherent requirements, capabilities and limitation; hence, much research is needed.

Needed are more accurate charting, better knowledge of distribution and types of sites, in relation to geophysical and biological resources, and better understanding of environmental phenomena. These require more and better research and engineering efforts.

PLANNING, MANAGEMENT, AND RESEARCH

Those concerned with design, construction and maintenance of engineering projects must be aware of interactions between those projects and the environment (a) which surround them or (b) with which they interact, near or far. Projects improperly designed or constructed may not survive the battering, erosive, corrosive or other destructive forces to which they are subjected. Further, they may not accomplish their intended tasks and may even destroy some other environment, resource, or value. Economic losses from ineffectual works in the coastal zone are enormous. Many calculations by military, naval, and civil engineers over the years bear this out. Damage has also been extensive.

Much effort and wealth has been expended to reduce or avoid destructive effects. These include boring and fouling organisms; undermining and battering effects of moving water and winds; corrosive actions of salt water; and obliterating effects of waterborne or aeolian sediments on the works of man. We have made headway and, proportionately, have reduced these effects. Yet the competition continues and much improvement is possible and necessary.

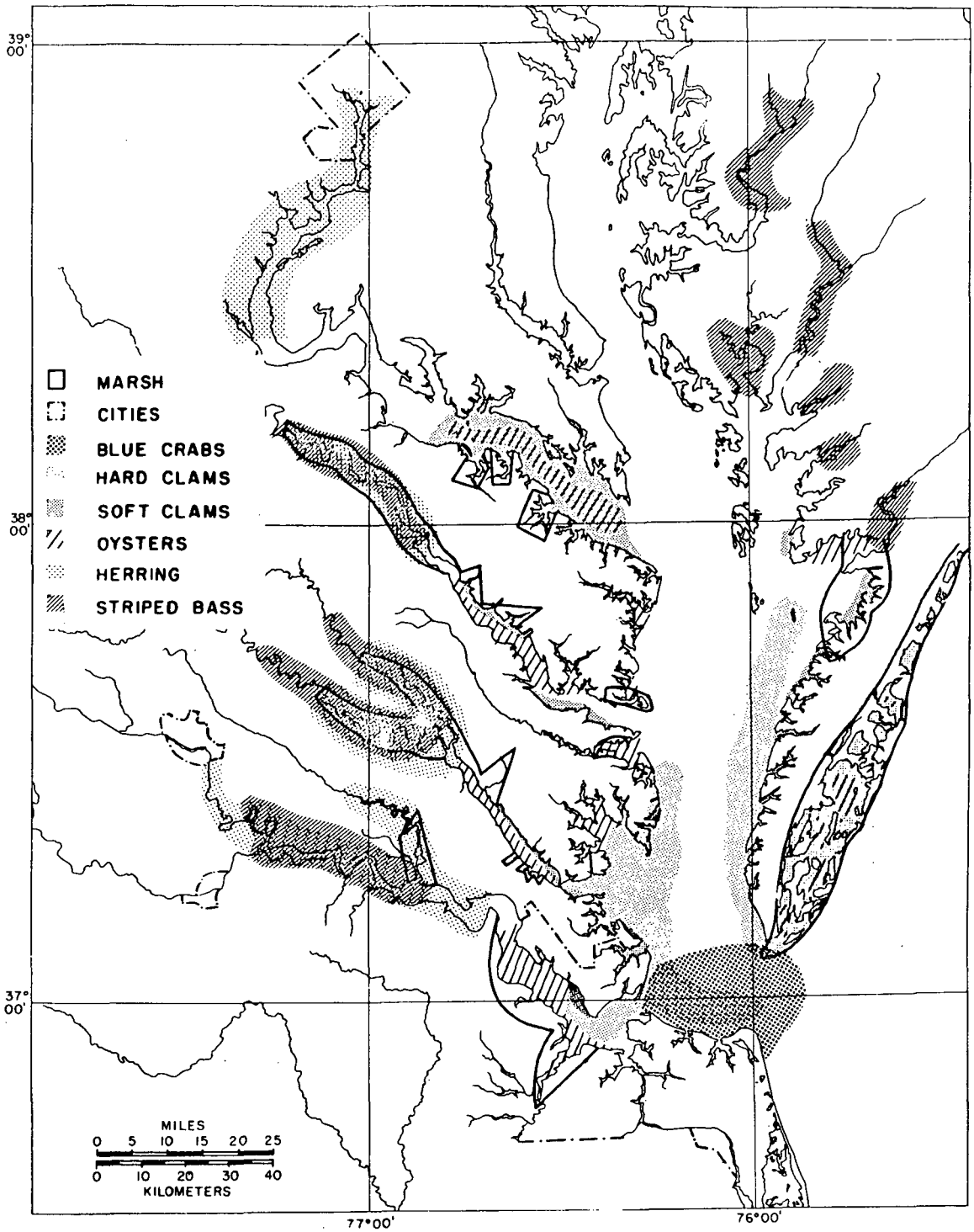

Figure 5.–Disposition of certain important ecological and population features in the lower Chesapeake Bay.

Logical and practical as they usually are, engineers are mindful of the need to understand the milieu in which they and their works must operate. It is important to industry and commerce and the public that engineers be fully apprised of the ecological or environmental factors involved. The greater the level of ignorance extant on this score, the greater the economic cost of engineering sound structures or operations. Overdesign and overconstruction have been the only sound alternative or means of compensation available. But overdesign and overconstruction cost money—usually large sums we can ill afford. In terms of the private and public good, the tighter the design and construction details, the lower the costs of marine projects. Conceivably, a greater number can be accomplished with the same money, if a greater number is an alternative.

Clearly, the engineering fraternity working in the marine environment or with their resources needs whatever help science and technology can render. This includes help from the environmental sciences as well as from applicable remote sensing technology.

From the public vantage point, planning and management of environments and resources of the Chesapeake Bay and adjacent waters are paramount activities. Many local, state, regional and federal agencies devote considerable effort and resources to these tasks. See, for example, the list given in reference 9.

That much remains to be done despite this public-supported effort has been clearly established during the last several years. Numerous studies have concluded that the growing multiuse problems and pressures, including those surrounding engineering projects and mining activities, must be more effectively treated. These studies range from the multivolume studies of the Stratton Commission (ref. 10) to the records (some as yet in process) of the Coastal Zone Hearings of the Subcommittee on Oceanography of the Senate Committee on Commerce, and the Subcommittee on Oceanography of the House Committee on Merchant Marine and Fisheries. One such Congressional Report, that of the Committee on Merchant Marine and Fisheries, was published in 1969 (ref. 11). Others are destined to follow this year. Numerous other state, federal and privately financed studies have reached the same conclusions. There is, thus, ample basis for concluding that planning and management of the resources and environments of oceanic waters and of the coastal zone are primary tasks which must be facilitated.

Planners, public and private, practical and theoretical, find it necessary to have comprehensive knowledge of the systems with which they deal. Those concerned with planning (a) for allocation and user complex environments and resources and (b) for development of complex or important engineering activities are especially dependent. Planners must be aware of the capabilities of the environment to provide benefits and yield resources. They must also be aware of their limitations as well as capabilities to cause mischief and damage. This requires basic environmental and resource information and knowledge of the results of past planning and management efforts.

Management—the overall activity which involves information acquisition and evaluation, planning and control operations—also requires historical and contemporary information about the environments and resources for which it is responsible. These must be allotted and used, allotted and supervised, or managed. Clearly, the original, as well as the digested and integrated data of research are needed, as are timely status reports from appropriate feedback systems.

Both planners and managers must understand the interactions between natural environments and resources, and the works, needs, and activities of man. All sources and means of acquiring information should be available and exploited.

Since much basic information about the environments and resources of the Chesapeake Bay region remains to be assimilated and adapted, basic and applied research and engineering development are needed. Because planning and management are dynamic processes, appropriate and adequate evaluation or monitoring capabilities with feedback are essential.

In situ and remote sensing from distant vantage points offer much to the researcher, planner, and manager interested in environments and resources. The advantages of in situ sensing of environmental conditions are analogous to electrocardiograms in diagnosis and treatment of a heart patient. Intermittent or continuous measurements of important parameters is an essential part of research. Measurements are also important to the monitoring and feedback phases of management, and to the evaluation of planning efficacy.

Some people do not consider in situ sensing and remote sensing as being the same thing. The sensor may be emplaced some spatial distance from the eventual destination of the data, and they prefer to retain the phrase "remote sensing" for sensing from a distance. In the latter configuration, the subject and the sensor, itself, are

separated geographically. However one decides this question, it is clear that both types of systems, contact and non-contact, may require instrument design and handling capabilities of the highest order. The National Aeronautics and Space Administration has become noteworthy in its instrument development capabilities.

Despite the recent perfection of sophisticated space exploration, remote sensing is not new to environmental and resource planning and management. Aerial photography has long been used in land-use planning, erosion studies, highway routing, forestry operations, wildlife census, fishery monitoring, fish finding, and in other management or engineering and research operations. There is no question of its utility.

There is also little question that some of the newer remote sensing devices such as infrared thermometers, radar, laser gauges, multispectral sensors and other devices that can be mounted aloft would be increasingly useful. These can be mounted in low-flying, intermediate and high altitude aircraft, rotary-wing aircraft, and tethered or free-floating balloons. Questions do exist, however, concerning what is being sensed, recorded and reported in many instances. Often we know that something is being sensed but do not know exactly what it is or, more frequently, its significance in terms of location and time, accuracy, and precision. Much well-designed and executed work remains to be done to more clearly answer these questions before the full utility of remote sensing in resource planning and management activities will be clearly established. Concerted efforts at acquiring meaningful ground data are required. These seem most difficult to plan, finance, and prosecute.

Many sensors which have been developed can be mounted and operated from spacecraft. All are familiar with the excellent color and black-and-white video and photographic images that have been obtained from manned and unmanned space flights. Utilization of airfoil-level (U-2 aircraft) sensor images and images from space platforms in weather research and prediction and in other activities is also well known. Apparently we are not yet clear, however, on the significance and utility of space images in actual planning and management and engineering activities in the coastal zone. It seems axiomatic that the further removed from the Earth's surface the sensor is, the less detailed and accurate will be its images. But in fields such as this, axioms are frequently not as universal as postulated. Technological breakthroughs may further be accomplished that render high altitude and space observations more useful for particular purposes.

COMMENTS ON REMOTE SENSING AND CHESAPEAKE BAY

In the research and development phases of the operations of our marine environmental and resources management system, remote sensing would seem to have certain potential. Space and high altitude observations will be useful. Visible region spectral signatures could be used to study injections and dispersion of sediments and detritus from tributaries into larger bodies of water, from outfalls and from bays and rivers to the ocean. These signatures will also be useful in directly tracing dispersion of certain pollutants and phenomena such as natural slicks and fish.

Tracking of water colored by suspended silt and other materials coupled with infrared radiometry and other remote imagery are useful analytical techniques in certain circulatory and temperature studies. A critical need in marine research is development or adaptation of remote imagery techniques that will permit better studies of circulation patterns in the Bay area. Aerial sensing, coupled with drogue and dye releases and other surface activities, will greatly enhance these activities.

Should techniques be perfected and employed in time, they may be useful in the design, verification, and later use of the Chesapeake Bay Model.

As indicated earlier, it is not my purpose to explore the possible applications of remote sensing to planning and management of engineering activities in the Bay. I prefer to leave those subjects to the group discussion to follow since others with far more experience in the technical aspects of remote sensing will be involved.

A stress must be laid upon the need for adequate ground truth acquisition. It is not enough to develop and fly an instrument system. We must know what the instrument is sensing in all four dimensions, or in as many dimensions as possible. And we must recognize accuracy, precision, and significance of the measurements or readings. This most crucial phase of remote sensing systems development has been neglected. Even after more than a dozen years, the utility and possible significance of infrared thermometry in oceanographic research has not been fully established, to my knowledge.

The utility of aerial observations made at low altitudes is clear. What must be accomplished in objective, thorough, experimental fashion with full controls is a stepwise examination of specific remote sensing techniques at set altitudes of 1000, 5000, 20 000, 60 000, 120 000 feet and orbital altitudes or at other suitable increments. Along with simultaneous ground truth observations, these experiments would establish significance of intermediate- and high-altitude as well as space observations of natural phenomena, a most essential aspect.

Considerable attention has been given to priority problems and needs in coastal zone management and in coastal zone research by several scientists at the Institute at large and in its Remote Sensing Laboratories. This joint effort between remote-sensing experts, environmentalists, and other oceanographers resulted in the comprehensive report of J.C. Munday, et al. (ref. 12) which can be consulted for greater detail.

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